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Translated Abstract

RESEARCH ON MOLYBDENUM DISULFIDE AS A LUBRICANT - (U.S.S.R.)

By I. Y. Alzhitz and L. N. Sushkina

This paper describes tests conducted by the authors, comparing molybdenum disulfide lubricants imported into the Soviet Union and molybdenum disulfide lubricants compounded on the basis of Russian lubricants containing Chinese MoS_2.

The imported lubricants were MOLYKOTE Types Z, G, M-77.

The Soviet experimental products were made by a research establishment known as VNINP.

The experimental lubricants are described as follows:

Product Designation	Description
VNINP No. 1	Paste, containing 70% MoS_2 of Red Chinese origin; particle size 1 to 60 microns; in 30% silicone base
VNINP No. 4	Allegedly equivalent to Molykote M-77
VNINP No. 8	Grease, allegedly superior to MOLYKOTE Type G
VNINP	Paste, containing 40% MoS_2 of Red Chinese origin; particle size 1 to 60 microns; indigo derivative; polymethyl-phenyl siloxane liquid
VNINP PMFS	Paste, containing 40% MoS_2 of Red Chinese origin; particle size 1 to 60 microns.
VNINP Cyatim	Cyatim lubricant containing MoS_2 powder
VNINP Solidol	Cup grease
CHINA Moly	Powder, 1 to 60 microns

Investigations on the addition of MoS_2 to oils have been announced.

(1) Identification of Research Personnel

The following Soviet research personnel are reportedly engaged in the development of molybdenum disulfide lubricants in the U.S.S.R.:

A	N. N. AFANASOV V. K. AKUNOVA (Azerbaidzhan) L. Y. ALSHITZ
B	I. D. BEZBORODKO
C	V. D. CHISTYAKOV L. A. CHETNYAN
D	P. F. DERYAGUIN G. F. DYACHENKO
E	---
F	L. A. FEYGINA (Azerbaidzhan)
G	---
H	---
I	G. B. INDENBAUM
J	---
K	O. F. KREIN M. I. KALININA F. I. KIRPICHNIKOV O. E. KESTNER N. G. KONSTANTINOVA E. Y. KUYTIER G. S. KRIVOSHEIN V. P. KOCAYEV A. L. KOWSLOWSKI V. I. KONOPLINA I. M. KRUGLIY
L	V. A. LISTOVA
M	O. E. MOROZOVA S. V. MARKIN O. N. MURAVKI (Tsmitkesh) Y. D. MAKEYEVA K. M. MIKHAYLOVA
N	---
O	Y. M. OPARINYA
P	V. Y. POPOV I. M. PAVLOV L. N. PANSHINIM
Q	---
R	V. I. ROMANOVSKIY A. N. RESHETKINA Z. S. RUBTSOVA A. V. RYABCHENKOV
S	A. G. SPEKTOR Y. R. SHOR N. A. SUVOROVSKAYA K. A. SHAROV A. S. SHEIN L. N. SUSHKINA L. N. SENTURIKHINAYA Y. B. SKEPNER (Balkash)
T	---
U	---
V	P. F. VARDZYAKOM V. A. VISHNYSKOV B. B. VINOGRADOV
W	S. G. WEYSMAN
X	---
Y	A. S. YERMILOV (Azerbaidzhan)
Z	A. N. ZELIKMAN A. L. ZAKHAROVA A. A. ZHDANOV

(2) Plant Information

East Kounrad Mine

The East-Kounrad deposits supply most of the Soviet powder. The facilities include crushing and sifting operations and chemical treatment (dissolving of impurities), as well as a flotation process.

As a result of the purification, the general content of impurities was lowered to 1.4%. The specialist on this purification process is Y. B. SKEPNER. A distinguishing trait of MoS_2 from this deposit is the presence of tungsten trioxide in the crystalline lattice of molybdenite, which is not eliminated by the applied purification method. Process diagram is available on request. The following table shows the results of the purification process.

Composition of Molybdenite

Element	Content, %, before	Content, %, after
Molybdenum	38.98	59.6
Sulfur	23.62	39.0
Tungsten Trioxide	9.74	0.97
Silica	30.66	0.04
Iron	0.64	0.2
Arsenic	0.003	absent
Phosphorus	0.03	absent
Calcium oxide	9.54	0.06
Magnesium oxide	0.25	0.03
Aluminum oxide	0.93	0.04
Copper	0.01	absent
Carbon dioxide	1.6	absent
Oil and moisture	0.8	0.03
Total	100.803	100.00

Research & Development (R&D)

Some of the experimental lubricants are developed at the "V. V. KUYBYSHEV" SCIENTIFIC OIL RESEARCH INSTITUTE in AZERBAIDZHAN. The State of Azerbaydzhan also has molybdenite deposits.

The Institute uses Amsler and 4-Ball Testers. Products are made with (1) M-10 Vibro-Mill (dispersion of moly by mechanical grinding); (2) Jet-Mill (4-disc homogenizer); and (3) Ultrasound (dispersion in ethyl alcohol). Research personnel include L.A.FEYGIN, V.I. AKUNOV, and A.S. YERMILOV.

(3) Operational Data

Product Information

Designation	Description
VNIY-NP No. 1	Paste, containing 70% MoS_2 of Red Chinese origin, particle size 1 to 60 microns; 30% silicone base
VNIY-NP No. 4	Allegedly equivalent to M-77
VNIY-NP No. 8	Grease, allegedly superior to G
VNIY-NP	Paste, containing 40% of Red Chinese MoS_2; particle size 1 to 60 microns; indigo derivative; polymethyl-phenyl siloxane liquid
VNIY-NP PMFS	Paste, containing 40% of Red Chinese MoS_2; particle size 1 to 60 microns
VNIY-NP TSYATIM	TSYATIM lubricant; containing MoS_2 powder; developed in Azerbaydzhan.
VNIY-NP Solidol	Cup Grease
VNIY-NP No. 225	Lubricant
TSYATIM No. 222	TSYATIM lubricant, containing 10% MoS_2
CHINA-Moly	Powder; 1 to 60 microns

The lubricants described above were tested to obtain comparative data. The reference lubricant imported into the Soviet Union was MOLYKOTE (Types Z, G, M-77).

The two series under investigation were VNIY-NP and TSYATIM.

TRANSLATION (Preliminary Draft)

RESEARCH ON MOLYBDENUM DISULFIDE AS A LUBRICANT - (U.S.S.R.)

By I. Y. Alzhitz and L. N. Sushkina

1. Introduction

The points of friction, which work under conditions of high and low temperatures, aggressive media and under other difficult conditions, thus far are not safeguarded by effective lubricants.

These difficulties become especially evident for those points, where liquid friction cannot be maintained or guaranteed under conditions of a boundary lubricant.

The oils and lubricants marketed in the USSR have a very limited range of application as to temperatures (from - 25° - 30° to 180°- 200°C).

To the areas of friction, which till now have not been safeguarded by an effective lubricant, one may ascribe all oscillating bearings operating in the range of high and low temperatures, the parts of friction, working under conditions of small, relative motion and of considerable, specific pressures (conditions for the formation of fretting corrosion) and many more.

For such conditions, according to literature data, it is expedient to apply materials, which on the surfaces of friction favor the formation of a solid film, which then serves as a lubricant. The control of the efficiency of the application of lubricants on the basis of molybdenum disulfide (antifrictional and protective properties) under different conditions was the aim of this work. Natural molybdenite of a high degree of purification and dispersion is used as a lubricant.

Molybdenite, the natural form of molybdenum disulfide appears in many areas, but not all deposits are suited for processing. A big portion of the demand for MoS_2 abroad is satisfied at the present time by the mines in Colorado (U.S.A.); there are also deposits of molybdenite in the USSR.

Reducing molybdenum disulfide from molybdenite is technologically complicated.

The problem of its purification and of the technology of industrial manufacture has to be solved by other organizations and is not the object of this article.

Basically, imported molybdenum disulfide was used to test methods and effectiveness of the application.

2. The Structure and General Properties of MoS_2, (Literature Survey).

Molybdenum disulfide, used for lubricants, according to data by the majority of authors, must be natural. Synthetic MoS_2 possesses weaker lubricating properties.

Basically, molybdenite forms flat, thin, very flexible soft laminea, slippery to the touch, resembling graphite and leaving traces on paper. It is crystallized in a hexagonal system. The hardness according to MoS_2 ranges from 1 to 2. Specific weight 4.7 - 4.8 gram/cm^3. The melting point is 1185°. At 1100° in a vacuum MoS_2 is decomposed into molybdenum and sulphur.

The bond of sulphur with molybdenum is very durable, the bond of sulfur with sulfur, in contrast, is relatively weak. Therefore, for the sliding of one elementary lamina of MoS_2 over another, very small tangential forces are required.

The bond of the molecules of molybdenum disulfide with a metallic surface takes place due to free energy, present on the clean metallic surface, which explains the adsorption on the surface of very fine particles of molybdenum disulfide.

For the application of MoS_2 as a lubricating substance, its chemical and thermal stability are very significant. MoS_2 does not dissolve in cold and boiling water, nor in usual solvents, in kerosene or synthetic lubricating substances. MoS_2 is affected only by aqua regia and chlorine. Pure oxygen, even at room temperature, oxidizes MoS_2, while oxygen in the air does not show any noticeable influence, under temperatures of up to 400°. Between the temperatures of 400° and 421°C, an extremely thin layer of MoO_3 is formed. Considerable oxidation occurs at 421°-455°C followed by swift transition to the trioxide of molybdenum. Thereby the thermal stability of MoS_2 as a lubricating material is limited, inasmuch as MoO_3 is an abrasive.

However, molybdenum disulfide continues to remain a lubricant to 525°C, until the entire layer of MoS_2 changes to MoO_3. For the application of MoS_2 as a lubricant, its purification from different impurities is very important, of which abrasive impurities are especially harmful (above all silica). The contents in MoS_2 of only 0.5% SiO_2 considerably increases wear of parts and deteriorates lubricating properties of molybdenum disulfide.

As a lubricating material MoS_2 is applied in the form of a dry powder, as well as in the form of different compositions with liquids. The methods of applying molybdenum lubricants are determined naturally by their different types.

MOLYKOTE lubricants marketed abroad can be applied in a dry form (Type Z and Microsize) by rubbing the powders into the surface of friction (by hand or in special tumblers), in the form of a dispersion of MoS_2 in a solvent with binders (as a paste with mineral oils, silicon liquids, diethers, and with polyalkylene glycols), and also an additive to mineral oils and consistent lubricants.

The preliminary, careful cleaning of the surface with solvents is a necessary condition for the application of the lubricant, MoS_2.

Another important factor for the safeguarding of the efficiency of MoS_2 is its particle size, which has to be of the same order of magnitude as the degree of unevenness of the metallic surface. The size of the particles must not exceed even the smallest unevenness and cavity in the surface.

Abroad, powders are on the market with different particle size; for instance, MOLYKOTE Z has size 1-60 microns, MOLYKOTE microsize 1-7 microns.

The basic areas for application of molybdenum disulfide are the parts of friction, where usual oils and lubricants cannot work because of high temperatures and pressures or of any kind of unusual environments, for example:

1) where high specific pressures, considerable friction, wear and seizure occur.
2) at extreme temperatures (high and low).
3) under conditions of aggressive or unusual media (rubbing parts immersed into hot or cold liquids).
4) under conditions, where mating parts, made of identical or similar materials (stainless steel with stainless, brass with brass, etc.) slide on one another.
5) at points with reciprocating motion and under conditions of small, relative motion of the mating surfaces (in this case MoS_2 inhibits fretting corrosion).
6) high friction, when starting a mechanism.

1. **This work was done in VNIMA by Oparinya, Y. M. and Semturikhinaya, L. N.**

7) application on rubber or in plastics, mating with metal.
8) for the improvement of the conditions of assembly and disassembly.

3. The Application of Films and the Manufacture of Pastes

For the applications of the films of molybdenum disulfide, we can use the MoS_2 powder directly when, according to the conditions of the application, it is possible to apply it on a part (the formation of a film under pressure). We can also form a film of MoS_2 by applying it on the metal as a suspension of the powder MoS_2 and solvent in the presence of a binder.

In this article both methods have been used. Together with MOLYKOTE Z Chinese molybdenite was applied. It should be noted that the Chinese molybdenite was filtered through a sieve of 270 mesh, which guaranteed the absence of particles larger than 60 microns. The resin which is the binding agent in the dry films of MoS_2, has to form a kind of a structure, in the fibers of which particles of molybdenum disulfide are located (if the hardening of the resins is not carried out under pressure); it contains a great number of pores and therefore consists of a great number of fine fibers. In this way, the structure of the binding agent as well as the unevenness of the surface, if they are in agreement with the dimensions of MoS_2, prevents their removal by the rubbing surface. The thermoreactive resins resulting from the reaction of poly condensation possess a porous structure after hardening; these resins were thus used as a binding agent. Moreover, polymerized resins were used.

Before the application of the films the metallic surfaces were thoroughly cleaned with alcohol and benzene until they had been completely drained, they were dried and heated to 40° - 60°. The prepared suspension of 80% MoS_2 and 20% resin in a solvent was applied in a thin layer with a small brush onto the surfaces, which were tested. After vaporizing the main part of the solvent, the parts were kept in a drying cabinet at a temperature of 120°-250°C for the duration of 2-3 hours depending on the resin used.

The preparation of the pastes was carried out in a homogenizer, which allows the compounding of MoS_2 to the optimum concentration (40%-50%). In preparing the pastes it was noted, that they form layers when standing. Therefore the question about the choice of the stabilizer arose.

The use of a stabilizer in the production of lubricants on the basis of MoS_2 is necessary for the prevention of an accumulation of dispersed particles of MoS_2 in the process of pulverization and after the pulverization, and also for the stabilization of MoS_2 in a dispersion (mineral oil, silica liquids, and others). In doing so, the stabilizer by itself (or in a lubricant) must be stable in temperatures of up to 400° and must not show any corrosive influence on the materials of the parts, which were exposed to the lubricant. For the manufacture of the pastes, oleic acid and Resin K-43 were used as stabilizers.

4. METHODS OF TESTING. The lubricating properties of molybdenum disulfide were examined on a few testing machines, on which characteristics were observed, such as the coefficient of friction, the durability of the lubricating film, anticorrosive properties, and the stability against wear at a high temperature.

The tests were intended to examine the properties of the lubricant under specific pressures of 3000-8600 kg/cm^2 and under elevated temperatures of up to 350°C. Corresponding to different types of use of MoS_2 in industry, tests were conducted with the powder type and the paste type, and of films of MoS_2 with a binding agent, which was temporarily applied to surfaces of friction.

For comparison, colloidal graphite was tested (in different types), which (as is shown above) has some properties resembling molybdenum disulfide and is also used as a lubricating material.

a) Method of Testing on the "Mi" Machine. On the Mi Machine (of the Amsler type), the tests were carried out on samples in the form of rollers ø 40 mm, b=10mm, oscillating friction with 10% sliding (see diagram of the test, Fig. 1).

As the basic characteristic in the given tests, served the diagrams of the moment of friction, obtained by a recording device on the machine was used. The presence of a film of MoS_2 on the surfaces of the rollers during the test was determined by the amount of friction. When friction was notably increased (about to a corresponding friction coefficient of 0.3), the test was regarded as finished. The indicated magnitude f=0.3 corresponds to a friction coefficient of clean unlubricated surfaces of rollers (under other equal conditions of the test).

Usually, on the Mi Machine in the tests of the samples with the lubricant constantly supplied, the friction coefficient and wear (weighing) were also determined.

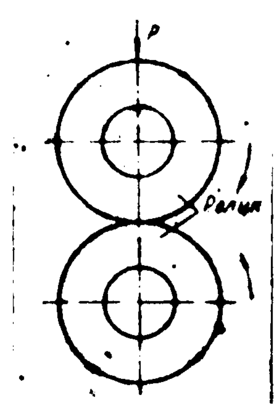
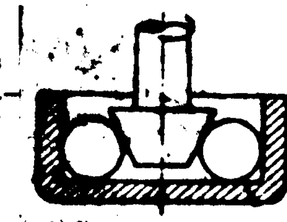


Fig. 1. Diagram of the tests of samples on the Mi Machine.

However, in the case of the tests with molybdenum disulfide it was impossible to figure out the wear, because the characteristic feature of this lubricant is the formation of a solid film of MoS_2 on the surface of the metal and, unless this film is destroyed, losses of weight do not occur. The rollers for all tests were made of steel 45, hardened to hardness R_c=48-50 (except the phosphocted ones) with a cleanliness of the surface in the 7th class (except special tests to determine the influence of the degree of roughness of the surface).

In the tests, with the surfaces temporarily covered with films of MoS_2 with a binding agent, the rollers were tested under a given load. A roller coated with a film was working together with a clean roller. The method of testing the pastes was more complicated. In using the paste, it is usually applied onto the surface in sufficient quantity, being used gradually, renewing the film of MoS_2 on the rubbing surface of the metal. When a large quantity of the lubricant is used (this also refers to the powders), the durability of the film cannot be shown, and the following method of tests was accepted. The work surface of the rollers was thoroughly cleaned by gradual washing in benzene and alcohol (to permit firm bonding of the MoS_2 molecule with the metal). During the first 30 minutes, the rollers were working under a pressure of 3260 kg/cm^2 (according to Hertz). The lower roller in rotation caught the lubricant from the basin and on the friction surface a film of MoS_2 was formed. After that, the basin was removed, the tracks of the rollers were rubbed dry in order to eliminate <u>excessive absorption</u> during the test and they were put to the test. ----- The tests on the Mi Machine were carried out at room temperature.

b) <u>Method of Testing on a Machine with 4 Rollers</u>. The machine with 4 rollers serves for determining <u>antiwear</u> properties of the materials and lubricants. ---- The principle of the device is as follows. The rotating conical specimen under load adapts itself to 3 specimens, placed at an angle of 120° (see Fig. 2) in a reservoir filled with the lubricant. ---- The conical specimen is in contact with cylindrical specimens at 3 points. The load is applied in increments; after every test the diameter of the wear scar on the cylindrical specimen is measured with a magnifying glass. At every stage of the load the test is carried out on new surfaces (the conical specimen is changed). ---- According to the obtained data diagrams on the dependence of the amount of wear from the load are formulated. As a characteristic of the antiwear properties, the load at which seizure occurs was used,



<u>Fig. 2.</u> Diagram of the tests on the machine with 4 rollers.

1) The machine was constructed by P. F. Vardzyak, I. Y. Alshitz, V. Y. Popov, S. V. Markin.

i.e., the formation of a large wear scar. ---- The conditions of the test: the upper conical steel specimen (45), hardened; rollers - steel 45, Ø 12 mm; number of revolutions of the conical specimen - 360 rotations per minute.

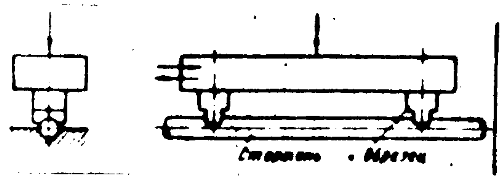


Fig. 3. Diagram of the specimens on machine PV.

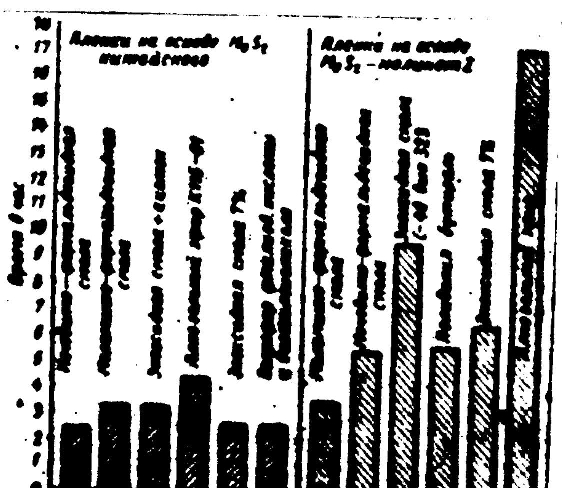
c) Method of Testing on the PV Machine. The PV machine is intended for tests of specimens on wear under intermittent movement under high temperature. --- The specimens with friction surface cylinder type are pressed down and sliding over a round, polished rod of steel R 9 with a hardness $R_c = 56 \div 58$, bolted in a stationary position. Two samples (see Fig. 3) are working simultaneously. An increase in temperature on the surface of friction is accomplished by electrical heating of the rod; the temperature is controlled by a thermocouple. The specimens and the rod are washed with benzene and alcohol, weighed on analytical scales, lubricated with the lubricant to be tested, and tested for an hour. The test is repeated 3 - 4 times. In addition to the loss of weight, linear wear and tear stops. -- Conditions of test: the material of specimens: steel 45; cleanliness of the surface: 5th class; specific load: 300 kg/cm^2; average speed: 5 m/minute; number of movements per minute: 60; temperature: 350°C.

5. RESULTS OF TESTS.

a) Tests on the Mi Machine. On the Mi Machine, i.e., under conditions of oscillating friction with 10% sliding, tests were carried out for the selection of a binding agent, for the determination of the influence of the cleanliness of the surface (on the specimens, coated with a film of the best binding agent), and of the influence of the temporary coating

Time of 8 hours

1. Urea-formaldehyde resin
2. Melamine-formaldehyde
3. Epoxy resin&acetone/resin
4. Alcoholic ether K115-01
5. Epoxy resin 7%
6. Polyether of Phthalic Acid & Diethylene Glycol



1) Melamine formaldehyde Re-/sin
2) Urea-formaldehyde resin
3) Epoxy Resin S-40 Wyp 323
4) Polyvinyl Butyral
5) Epoxy Resin 7%
6) Alcoholic Ether

(phosphated before the application of the film) on the properties of the films. ---- Powders and pastes were tested.

The results on the tests of the films, manufactured on the basis of Chinese MoS_2 with particle size of 1-60 microns and a concentration of 80% plus Molykote Z with different binding agents, are represented in Fig. 4 and in Charts 1 & 2. The tests were carried out under a load according to Hertz, equal to 3260 kg/cm^2. The rollers were made of steel 45, hardened to hardness of R_c=48 +-52; cleanliness of the rollers: 7th class.

Chart 1

Results of Tests on the Mi Machine; Rollers coated with films of Chinese MoS_2.

Binding Agents	Average to increase	Time to increase of friction coefficient	Average time
Urea-formaldehyde resin	0.14 0.11 0.11	3 hours 2 hours 15 min. 2 hours	2 hrs.25 m.
Melamine formaldehyde resin	0.13 0.11 0.07 0.14 0.14 0.11 k 0.09 0.10	4 hours 4 hours 4 hours 3 hours 3 hours 3 hours 3 hours 45 min. 2 hours 30 min.	3 hrs.20 m.
Epoxy resin - acetone	0.11 0.15 0.14	3 hours 4 hours 3 hours	3 hrs.20 m.
Alcohol ether K115-01	0.15 0.10 0.14	4 hours 4 hours 15 min. 5 hours	4 hrs.25 m.
Epoxy resin 7%	0.15 0.18 0.10	1 hour 30 min. 3 hours 3 hours 30 min.	2 hrs.40 m.
Polyether of Phthalic acid + of diethelene glycol	0.04 0.11 0.07 0.13	3 hours 30 min. 2 hours 30 min. 2 hours	2 hrs.40 m.
Castor glyphthal drying, FK-42v		30 minutes	

The films on the basis of Chinese MoS_2 had an average friction coefficient, approximately equal for all binding agents with a fluctuation in the limits of 0.09 to 0.18. According to the durability of the film slightly better results were obtained when alcohol ether K-115-01 was applied as a binding agent.

The films, manufactured on the basis of Molykote Z with the same binding agent, gave a smaller friction coefficient for 4 resins; on the average 0.07-0.09 (melamine and urea formaldehyde, epoxy S-40 and polyvinyl butyral); 7% for epoxy; and for

Chart 2

Results of Tests on the Mi Machine
Rollers coated with films of MoS_2-Molykote Z.

Binding Agents	Average to increase	Time to increase of friction coefficient	Average time
Melamine formaldehyde resin	0.08 0.14 0.08 0.07	2 hrs. 2 hrs. 30 min. 5 hrs. 5 hrs.	3 hrs. 45 min.
Urea formaldehyde resin	0.08 0.04 0.08 0.05 0.08	4 hrs. 5 hrs. 45 min. 4 hrs. 5 hrs. 9 hrs.	5 hrs.35 min.
Epoxy resin S-40 WYP/323	0.07 0.07 0.07 0.09	8 hrs. 30 min. 9 hrs. 12 hrs. 30 min. 9 hrs.	9 hrs.45 min.
Epoxy resin polyvinyl butyral	0.07 0.08 0.07	7 hrs. 9 hrs. 1 hr. 30 min.	5 hrs. 50 min.
Epoxy resin 7%	0.06 0.11 0.12	10 hrs. 3 hrs. 30 min. 6 hrs. 30 min.	6 hrs. 40 min.
Alcohol ether		17 hrs. 30 min. 23 hrs. 30 min. 11 hrs.	17 hrs. 20 min.

alcohol ether, coefficients of friction from 0.09-0.16 were obtained.

However, according to the duration of the test film, alcohol ether showed the longest time, on the average 17 hours, while films with other binding agents were working from 3.5 to 9 hours.

Tests of films from a clean binding agent (for control) showed that such films do not possess lubricating properties;

the friction coefficient at once begins to increase.

In comparing, as a whole, the results of the tests on the films with a basis of Molykote Z and Chinese MoS_2, we can see that according to the friction coefficient and according to the life the films on the basis of Z gave better results.

The results, obtained according to the determination of the influence of cleanliness of the surface, are listed on Chart 3 and in Fig. 5. The rollers were treated according to 3 different classes of cleanliness of the surface and coated with films of Molykote Z and alcohol ether.

The best result was obtained for the surface with a cleanliness of the 5th class, i.e., for the surface with a high degree of roughness (in the shown limits), when they were coated with films of MoS_2 with the size of the particles from

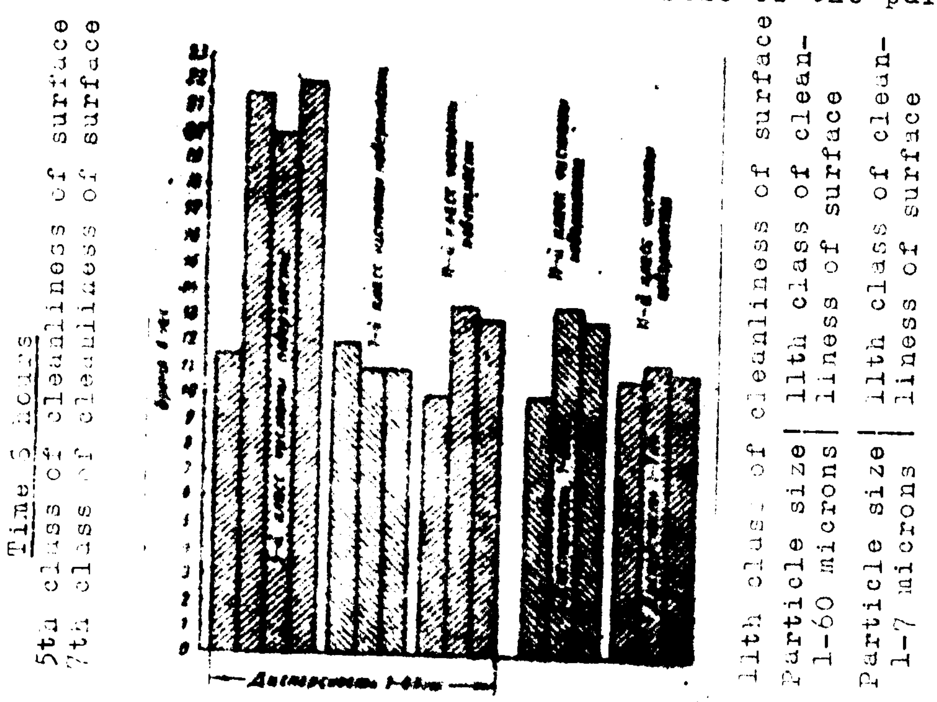


Fig. 5. The influence of cleanliness on the treatment of friction surface and particle size of MoS_2 on the life of the film ($R=3260$ kg/cm^2).

1-60 microns.

The data on tests of specimens with surfaces, treated according to the 11th class of cleanliness, coated with films of MoS_2 of 2 kinds of particle sizes: Molykote Z (1-60 microns) and Microsize (1-7 microns), listed on the same Chart 3 and Fig. 5. It can be seen from these data that, in case of great cleanliness in treatment, a smaller size of particles of the powder decreases the friction coefficient, but does not show any influence on the life of the film.

Chart 3

Results of Tests on the Mi Machine
Rollers with a different degree of cleanliness of the surfaces

Cleanliness of the surface	Average to increase	Time to increase of friction coefficient	Average time
5th class	0.03 0.03 0.03 0.04	11 hrs. 30 min. 21 hrs. 30 min. 20 hrs. 22 hrs.	18 hrs.45 m.
7th class	0.09 0.13 0.16	12 hrs. 11 hrs. 11 hrs.	11 hrs.20 m.
11th class	0.09 0.09 0.13	10 hrs. 13 hrs. 30 min. 13 hrs.	12 hrs.10 m.
11th class of cleanliness of surface, film-alcohol ether +Microsize (particle size of 1-7 microns).	0.06 0.08 0.05	10 hrs. 45 min. 11 hrs. 20 min. 11 hrs.	11 hrs.

The preliminary phosphating (Fig. 6) increased the life of the film only slightly. The tests with the different pastes, manufactured on the basis of MoS_2, of colloidal graphite MS, and the lubricant Cyatim 221 (Chart 4 and Fig. 7), under a load of 3260 kg/cm^2 revealed the largest life of the film, which is formed by a paste, Molykote G (after rolling under pressure). ---- This film was functioning for the duration of 14-20 hours The other films, formed by other pastes, were functioning within limits of 30 minutes to 4.5 hours.

The friction coefficients were of the same order (0.07-0.01) as in the case of dry films (except paste Vniinp #1). In this way, under a load of 3260 kg/cm^2, even lubricants which do not contain MoS_2 gave a film which was functioning for some time. ---- Under a load equaling 8,600 kg/cm^2, the friction coefficient for all pastes decreased (equal to 0.05-0.09). From Fig. 8, it can be seen that on metallic surfaces the lubricant Cyatim did not leave a film capable of functioning under pressure of 8,600 kg/cm^2. The film of colloidal graphite MS was working for 8-10 minutes. The addition of 10% MoS_2 to the lubricant Cyatim increased the durability of the lubricant to

20-40 minutes. Molykotes M-77 and G were functioning for up to 2 hours; but pastes Vniinp #4 and #8 even more (up to 4 hours).

The tests carried on with the films, formed on the surfaces of friction, in working with the powders of MoS_2 + graphite confirmed the data of foreign research personnel about the advantages of MoS_2 over graphite under conditions of average and high pressures (see Chart 5 and Fig. 9). When the pressure equaled 3260 kg/cm^2, the graphite lubricant functioned better than MoS_2, as far as the friction coefficient and as far as the life of the functioning of the film was concerned: f of graphite ~ 0.06; f of molybdenum disulfide 0.14; the average life of the graphite film ≥ 20 hrs., on the film z ~ 6 hrs.

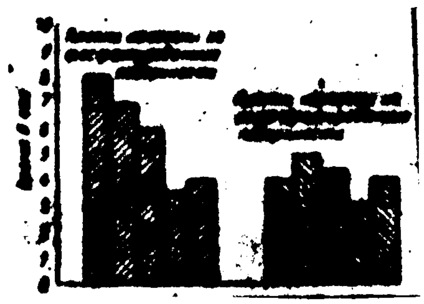
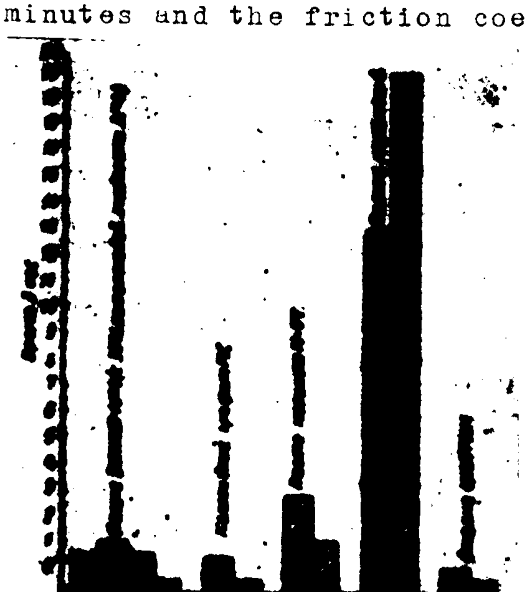


Fig. 6. The influence of preliminary phosphatization on the durability of the film (P= 3260 kg/cm^2).

However, under high pressure, equaling 8600 kg/cm^2, one gets the opposite picture. The friction coefficient in the case of lubricant Z is reduced to 0.04, the film is kept for the duration of 3-4 hours; when lubricating with graphite the film does not even last for a few minutes and the friction coefficient rises from 0.12 to 0.37.



1 - Time 6 hours.
2 - The paste Vniinp #1 (with 30% silicone liquid #4).
3 - Colloidal graphite MS.
4 - Paste of Molykote M-77.
5 - Paste Molykote G.
6 - Lubricant Cyatim.

Fig. 7. The life of the films formed with different pastes (P=3260 kg/cm^2).

Results of Tests on the Mi Machine, if lubricating with pastes (method of tests: 30 minutes; the rollers are lubricated by the paste under P=3260 kg/cm^2; after that they are functioning on the formed film until the increase of the friction coefficient.).

Lubricant	P after work with paste in kg/cm^2	f Average	Time till the increase of the friction coefficient
Paste Vniinp #1 (70% MoS_2-Chinese, particle size 1-60 microns, 30% of silicone liquid #4).	3260	0.16 0.12 0.00 0.13	1 hr. 30 min. 2 hrs. 1 hr. 30 min. 30 min.
Colloidal graphite MS (in oil)	3260		1 hr. 20 min. 30 min.
	8600		10 min. 15 min.
Paste Molykote M-77	3260	0.10 0.07-0.2	3 hrs. 45 min. 2 hrs.
	8600	0.05	15 min. 20 min. 2 hrs.
Paste Molykote	3260	0.03	14 hrs. 20 hrs.
	8600	0.10 0.06	30 min. 15 min. 1 hr. 14 hrs. 45 min.
Lubricant Cyatim #221	3260	0.035 0.035	1 hr. 30 min.
	8600		2 min. 5 min.
Paste: 40% MoS_2-Chinese; particle size 1-60 microns and indigo residue of polymethyl-phenyl siloxane liquid #4.	8600	0.06 0.07 0.07	2 hrs. 50 min. 3 hrs.
Paste: 40% MoS_2-Chinese; particle size 1-60 microns PMFS (#8)	8600	0.08 0.09	3 hrs. 1 hr. 30 min.
Lubricant Cyatim + MoS_2	8600	0.03 0.05	20 min. 40 min.

The Chinese MoS_2 powder forms a film, the life of which is approximately half as much as in the case of Molykote Z.

The better performance of the powder Z and of the dry films on the basis of Z, in comparison with the Chinese MoS_2,

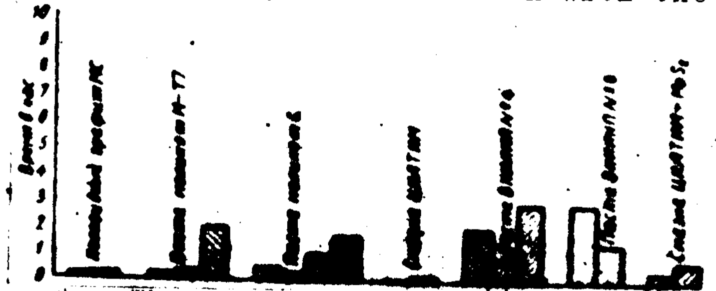


Fig. 8. The life of the films, formed by different pastes ($P=8600$ kg/cm^2).

may be explained by the absence of a stabilizer in the Chinese MoS_2 and also by the different, fractionary structure (MoS_2 particles in the powder, manufactured from Chinese molybdenite). The friction surfaces, when the lubricants were used, which contained MoS_2 and graphite, had a dull, smooth surface. ----

b) Tests on Machine with 4 Rollers. On the machine with 4 rollers pastes G, Л-77, colloidal graphite, and solicol were tested. The results of the tests are represented on Fig. 10. The imported paste G, manufactured on the basis of molybdenum disulfide, and colloidal graphite MS showed a good result. When the load was increased to [illegible]00 kg, the wear ... wear increased, but seizure did not occur. The worn surface was smooth, without laceration and considerable ...eres, which usually is observed in case of seizure.

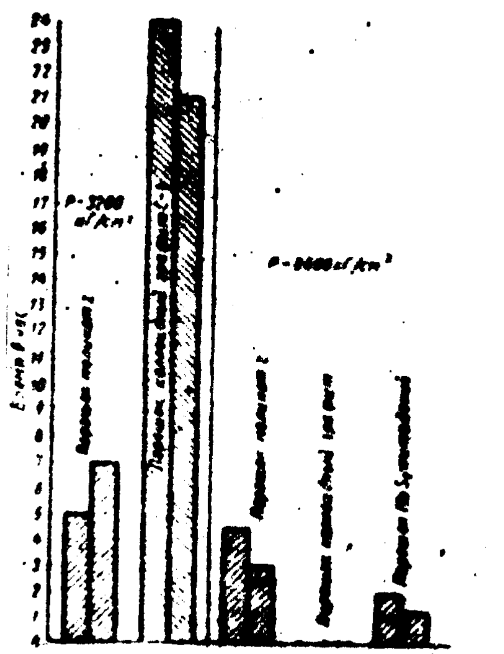


Fig. 9. The life of the films, which were formed by various lubricants in paste form.

Paste Л-77

Chart 5

The results of the tests on the Mi Machine when lubricating with powders (method of testing: 30 minutes; rollers are lubricated with a powder under P=3260 kg/cm^2, after which they work on the film, which has formed until an increase of the friction coefficient occurs), and solidol showed approximately

Lubricant	P after work with powders in kg/cm^2	f Average	Time till the increase of the friction coefficient
Powder-Molykote Z particle size 1-60 microns	3260	0.14 0.14	5 hrs. 7 hrs.
	8600	0.04 0.025	4 hrs. 30 min. 3 hrs.
Powder-colloidal graphite C 1	3260	0.06 0.06	24 hrs. (unfinished 21 hrs.)
	8600		–
Powder MoS_2-Chinese, particle size 1-60 microns	8600	0.05 0.04	2 hrs. 1 hr. 20 min.

the identical load carrying capacity (50-60 kg), in both cases a smaller one than with graphite and paste G. ---- Despite the smoothness of wear scars on the specimens, which were obtained when using lubricant M-77, the smoothness, which is so uncharacteristic for seizure, and the size of these scars on reaching the determined load was large. ---- In lubricating with solidol, the size of the wear scars under loads of more than 60 kg was somewhat smaller than in the case of the lubricant M-77; however, the surface of wear was uneven, with grooves, cracks, and wear on a part of the metal to the side of rotation. ---- We should note that we can use the sizes of the obtained maximum loads for the lubricants, which were tested on the machine with 4 rollers, only as comparative ones. The tests showed good anti-abrasive properties of paste G and of colloidal graphite MS. ---- Paste M-77, despite the ability to smoothen the friction surfaces under conditions of high specific pressures, showed a relatively small load carrying capacity.

c) <u>The tests on the PV Machine (intermittent)</u>. On the PV Machine the tested lubricants were: paste-Molykote M-77; colloidal graphite W-0 (aqueous); paste VNIINP #4 and solidol. The tests were carried out under a load of 300 kg/cm^2 and a temperature of 350°.

In Chart 6 and on the diagram (Fig. 11), data are listed according to weight and linear wear, according to each test (during 1 hour), and the average wear-out of 8-16 tests. The results obtained are pointing out an insignificant difference in the wear of the specimens when lubricating with 3 pastes under test.

Solidol, tested for comparison, gave only a somewhat higher rate of wear. ---- However, the process of wear proceeded in different ways: when lubricating with colloidal graphite W-0, and especially with solidol, the samples were squealing

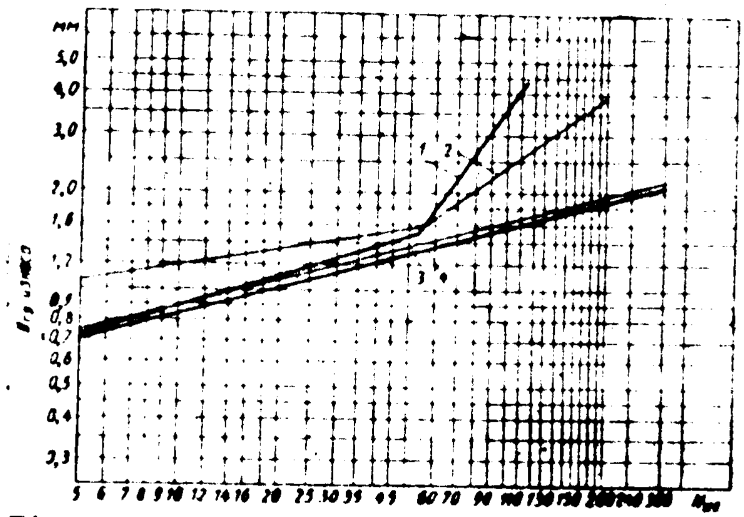


Fig. 10. Diagram of the load carrying capacity of different lubricants: 1 - paste M-77; 2 - solidol; 3 - paste G; 4 - graphite.

when rubbing occurred and both surfaces (of the specimen and of the rod) were split; when lubricant M-77 was used, the surfaces had a smaller scar, but separate specimens were squealing, while the lubricant VNIINP #4 gave a smooth surface on specimens and a surface not in the least damaged as far as the mating body was concerned (rod) and there was no noise during operation. ---- The tests which were carried out revealed that the "single" lubricant, applied to the friction surface not under pressure, nearly never prevents wear of the surfaces. Repeated lubrication for the first minutes of operation should be tested or, when possible, the application of the paste under pressure (preliminary run-in).

(1) The work was carried out by Dr. of Chemical Sciences, A.V.Ryabchenkov, and candidate of technical sciences, O.N. Muravki, - Corrosion Section TSNIITNASH.

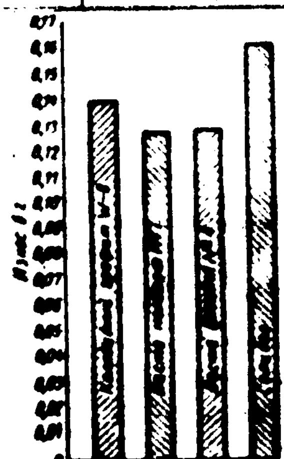
Chart 6

Results of Tests with Lubricants on the PV Machine

Lubricant	# of sample	# of test	Weight wear in g	Linear wear in mm
Colloidal graphite (aqueous) W-0	7	1	0.0953	0.23
		2	0.1127	0.22
	8	1	0.1453	0.18
		2	0.1307	0.26
	5	1	0.1900	0.42
		2	0.1161	0.22
	14	1	0.1871	0.34
	A V E R A G E		0.1396	0.267
Paste Molykote M-77	9	1	0.0932	0.18
		2	0.1436	0.30
		3	0.1289	0.30
		4	0.1415	0.31
	10	1	0.0826	0.24
		2	0.0830	0.10
		3	0.1049	0.31
		4	0.1294	0.28
	11	1	0.1838	0.47
		2	0.1224	0.22
		3	0.1923	0.45
		4	0.1869	0.32
	15	1	0.0932	0.28
		2	0.0832	0.13
		3	0.1315	0.34
		4	0.1297	0.25
	A V E R A G E		0.1269	0.28
Paste VNIINP #4	12	1	0.1156	0.26
		2	0.1058	0.23
		3	0.1439	0.30
		4	0.1096	0.25
	13	1	0.1108	0.29
		2	0.0999	0.28
		3	0.2036	0.42
		4	0.0759	0.21
	0	1	0.1728	0.40
		2	0.1260	0.27
		3	0.1905	0.44
		4	0.0867	0.19

Continuation

Lubricant	# of sample	# of test	Weight wear in g	Linear wear in mm
Paste VNIINP #4	16	1	0.1442	0.33
		2	0.1198	0.305
		3	0.1471	0.355
		4	0.0795	0.23
	A V E R A G E		0.1287	0.297
Solidol	7	1	0.1414	0.26
	8	2	0.1720	0.345
	5	1	0.1594	0.32
	14	1	0.1711	0.26
	A V E R A G E		0.1610	0.271



1 - Wear - g
2 - Colloidal graphite /MO
3 - Paste Molykote M-77
4 - Paste VNIINP #4
5 - Solidol

Fig. 11. Wear of the samples on the PV Machine (tested at 350°C).

d) Determining the Effectiveness of Molybdenum Disulfide as a Protective Means for Fretting-Corrosion. The work was carried out with the aim of finding protection against fretting-corrosion.

The phosphated and non-phosphated surfaces were tested. The marks of friction had the form of a ring.

Without the lubricant, the phosphated films were destroyed in the first minutes. The testing of such films, coated with paste of type G, was carried out under pressures of 250 kg/cm^2 amplitude of 0.524 mm and of a frequency of 112 cycles per minute. The films without destruction endured about 500,000 cycles. Under a pressure of 500 kg/cm^2, with an amplitude of 0.8 mm and a frequency of 112 cycles per minute, the films were not destroyed in the course of 124,000 cycles. With the same number of cycles, and under the same conditions, the unprotected specimens were severely damaged. ---- Tests of thin polyamide films (<0.2 mm) were carried out, which had been applied by spraying. These films were lubricated by paste G. ---- The films endured a pressure of 250 kg/cm^2, with an amplitude of 0.524 mm and a frequency of 112 cycles per minute for the course of 1,764,000 cycles. Destruction of the films, even after such prolonged tests, did not occur. The tests were stopped in order to save time. ----

This way, the application of molybdenum disulfide can, evidently, in these cases give positive and favorable results; the best effectiveness is obtained when using polyamide and molybdenum disulfide together.

6. TESTS ON SEMI-INDUSTRIAL ESTABLISHMENTS.

a) The Application of Molybdenum Disulfide when finned tubes are rolled cold. Research on the effectiveness of molybdenum disulfide in cold rolling of finned tubes made of aluminum stock, .Ø27 mm. ---- The temperature in the process of rolling rose to 140° and higher.

The effectiveness of the lubricant being employed is determined by the obtained maximum diameter of the tube being rolled. The increase of deformation occurred on account of reduction of friction and better conditions of flowing metal into the crack. ---- In dry operation, and when lubricant was applied in form of machine oil MS, the diameter of the tube was not more than 34-35 mm. ---- When using ample lubricant in the form of colloidal graphite MS (the lubricant was applied to axle-shafts), the diameter was 42 mm. ---- The very same diameter was obtained after a single application onto the instrument of a thin layer of paste G. The film was lasting on almost dry surfaces for the duration of several hours of operation. ----

b) Tests of MoS_2 in "Variators". The action of MoS_2 in the removal of harmful influence of fretting corrosion in "variators" was checked. Fretting corrosion represented one of the main causes of low efficiency of previous designs of "toroid spherical variators".

This corrosion led to the full loss of mobility of junctions in the "knots" of the "variators", where the loss of mobility is undesirable.

Lubrication was made with consistent grease 1-13. When using such lubricant for a few hundred hours of operation, the lubricant between parts dried up, surfaces showed corrosion, and it was possible to take off the glass only with the

1) Research was done by engineer F. P. Kirpichnikov.

aid of strong blows of a hammer. ---- For the determination of the possibility of application of MoS_2 for the prevention of fretting corrosion in the mentioned point of "Variator 2-T-6", both surfaces were rubbed with powder of molybdenum disulfide. ---- After 840 hrs of operation of the point of friction, on which MoS_2 had been applied, the mobility of the combination was good, the glass was easily removed from the traverse. ---- For comparison on the same point, colloidal graphite of the S-1 type was tested. ---- The mobility of the junction of this point, where colloidal graphite S-1 was employed (also after 840 hours of work), was impeded; the glass was taken off the traverse by the pressure of a screwdriver. On the surfaces spots of corrosion had appeared.

c) Tests on Lubricants on the Basis of Molybdenum Disulfide in Stamping. The tests were carried out on a laboratory press with an amplification of 25 m. On the stamping machine, heated to 400°, a disc Ø of 60 mm, 4 mm in height, was coated with a film of molybdenum disulfide, on the basis of Chinese MoS_2. On the disc, a sample of duraluminum AK-6, heated to 420°, was placed covered by the second disc with the same film of MoS_2, which had been applied to it. After that, the sample was deformed by the maximum effort of the press. ---- We can judge the effectiveness of the lubricant by the size of the wear of the specimens when they get deformed. According to the measure of the increase in the quantity of the deformed samples on a given disc, the degree of their deformation was decreased. ---- The results of the tests showed that the film of molybdenum disulfide possesses a sufficiently high lubricating ability, close to the lubricating ability of lubricant vapor + graphite, which is presently employed in the industry for forming of aluminum alloys. ---- However, the stability of the lubricant turned out to be insufficient, since during a second pressing together with a new specimen between the same discs the effect of the lubricant was strongly reduced (the relative reduction decreased in one case from 43 to 15%, in another one from 42 to 13%). ---- The obtained results showed the short duration of the effect of the application of the film of Chinese MoS_2 under conditions of hot punching. ---- Outside the films of MoS_2, Molykote of the type G(paste) was tested. ---- A good lubricating ability of the paste became apparent by only a single deformation of the specimen.

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1) The tests were carried out with a laboratory forge-press of Ts N I I T M A SH. The work was under the direction of candidate of technical sciences, E.R. Shor and candidate of technical sciences, I.Y. Alshitz.

CONCLUSIONS

1) The testing in normal temperature of lubricants on the basis of MoS_2 revealed their ability to form solid films on the surface of metal; films which endure a pressure of 8600 kg/cm^2 for a few hours.

2) The films of the lubricants not containing MoS_2 (graphite TS I A T I M 22, Solidol), do not endure such pressures.

3) In the case of loads from 3000 to 8600 kg/cm^2, the durability of the films (correspondingly):
   a) of the ones formed by powders of MoS_2 did not exceed 4-7 hours;
   b) of the ones formed by pastes - not less than 3-20 hours;
   c) of the ones employed with binding agents - from 4-17 hours.

4) The powder made from Chinese molybdenum gave worse indexes than Molykote G, apparently because of the absence of a stabilizer (we did not succeed in selecting an effective stabilizer for the dry powder).

5) The powder of colloidal graphite in pressures of up to 3000 kg/cm^2 gives better indexes than Molykote G.

6) The pastes of Molykote do not show advantages over pastes made by V N I I N P on the basis of Chinese MoS_2.

7) The use of the films under stress (preliminary rolling) gave a favorable result; the use of MoS_2 rubbed in by hand was negative.

8) The roughness of the surface, obtained both by mechanical treatment and artificially (by phosphating), favorable affected the work of the applied films when there was a corresponding size of MoS_2 particles. Specifically, with the dispersion of Molykote Z (1-60 mm), better results are obtained on surfaces of the 5th class.

9) The paste Molykote G and colloidal graphite M-C have good anti-abrasive properties in conditions of relatively high specific pressures.

10) The tests of the pastes in high temperatures (350°) on the laboratory machine and under industrial conditions, showed that the application of pastes is effective only at the beginning of the work and it is necessary to systematically renew the lubricant.

11) The conducted tests confirmed that molybdenum disulfide is a reliable means against fretting-corrosion.

12) Under considerable specific pressures and small velocities the lubricant on the basis of MoS_2 for the length of a short period of operation or in the case of systematical renewal possesses high antifrictional properties and can find

application in different fields of mechanical engineering, in the first place in areas of friction, functioning under conditions of an incomplete lubricating film.

13) The research carried out with T S N I I T M A S H to analyze molybdenum disulfide as a lubricating material did not give the effect anticipated from literature data[1]. It is possible that such results were obtained owing to the fact that MoS_2 is not sufficiently known by us in detail.

Such questions, which had not been dealt with, remained; such as, the choice of the stabilizer for the MoS_2 powder; the follow-up on the presence of the MoS_2 film on metals with physical-chemical methods; the tests in case of loads higher than 8600 kg/cm^2; the effect from additions of MoS_2 in mineral oil; anti-wear properties and others.

Therefore, one should examine this data as first insight into this material, and the conclusions may not be considered final.

One should indicate that MoS_2 in the USSR is a considerably more scarce product than graphite and, if the complication and expensiveness of its manufacture are taken into account, then one can make the preliminary conclusion about the advisability of using MoS_2 only in points where specific problems of operation exist.

[1] Alshitz, I.Y. The Use of Molybdenum Disulfide as a Lubricant (Survey of Foreign Literature). Journal of Mechanical Engineering #8, 1956.